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VOLUME DECREASE OF RUTOR GLACIER (WESTERN ITALIAN ALPS) SINCE LITTLE ICE AGE: A QUANTITATIVE APPROACH COMBINING GPR, GPS AND CARTOGRAPHY

ABSTRACT: VILLA F., TAMBURINI A., DEAMICIS M., SIRONI S., MAGGI V. & ROSSI G.C., *Volume decrease of Rutor Glacier (Western Italian Alps) since Little Ice Age: a quantitative approach combining GPR, GPS and cartography*. (IT ISSN 1724-4757, 2007).

The results of a dGPS assisted Ground Penetrating Radar survey made on Rutor Glacier (Aosta Valley, Italy) are discussed in this paper. The aim of the survey was to quantify the ice thickness and estimate the total glacier volume. The upper part of the basin was surveyed in 1996; in July 2006 this survey was completed in the lower part too. After the interpretation of the radar signals a model of the ice-bedrock interface was produced.

The glacier volume in different periods between Little Ice Age (LIA) and present days was estimated by difference between the bedrock model and three surface models previously generated. This allowed not only to analyse the ice volume melt in a time interval but also the percentage it represents on the whole glacier volume. The dGPS data were used both to georeference the radar tracks and to measure the ablation rate, by comparing them with former surface data. Furthermore, the dGPS tracks are intended to be the first step of a periodic series of measures for a geodetic mass balance evaluation.

By comparing glacier surface reconstructions obtained with different techniques and bedrock data, an ice volume loss of about 500 Millions of m^3 from LIA to 1975 was calculated, which represents a volume reduction of about 60%. From 1975 to present days another 50% of the remaining volume got lost. This resulted in a volume reduction rate of $-0,5\%yr^{-1}$ from the Little Ice Age maximum to 1975, a value of $-1,1\%yr^{-1}$ between 1975 and 1991 and a volume reduction rate of $-2,1\%yr^{-1}$ up to 2006.

KEY WORDS: Glacier evolution, GPR, dGPS, Mass balance, Rutor glacier, Italian Alps.

RIASSUNTO: VILLA F., TAMBURINI A., DEAMICIS M., SIRONI S., MAGGI V. & ROSSI G.C., *Variazioni volumetriche del ghiacciaio del Rutor (Alpi Italiane Occidentali) dalla Piccola Età Glaciale: un approccio quantitativo condotto attraverso analisi GPR, GPS e cartografiche*. (IT ISSN 1724-4757, 2007).

In questo articolo vengono descritti i risultati di un rilievo GPR/dGPS effettuato sul ghiacciaio del Rutor (Valle d'Aosta), il cui scopo era quello di quantificare gli spessori di ghiaccio lungo le tracce seguite e stimare il volume totale del corpo glaciale.

La parte più a monte del bacino è stata rilevata nel 1996 e nel Luglio del 2006 il rilievo è stato completato anche nella parte frontale. Dopo aver interpretato e collegato le tracce radar dei due rilievi è stato generato un modello dell'interfaccia ghiaccio-roccia ed è stato stimato il volume del corpo glaciale calcolando la differenza tra alcuni modelli di superficie prodotti precedentemente ed il modello del letto glaciale. Questo ha permesso di stimare le quantità di ghiaccio perdute negli intervalli di tempo considerati ed analizzarle come percentuale sul totale della massa rimanente.

I dati dGPS raccolti durante il rilievo GPR sono serviti sia per la corretta georeferenziazione dei dati radar, sia per un'analisi dell'ablation rate; tali dati sono infatti stati confrontati con il modello di superficie riferito all'anno 1991 e sono stati stimati gli spessori di ghiaccio persi per fasce altimetriche. Le intenzioni sono quelle di ripercorrere periodicamente la traccia del rilievo dGPS, per ottenere una serie di misure necessarie ad una valutazione del bilancio di massa con metodo geodetico.

Confrontando dati relativi alla superficie glaciale rilevati con metodi differenti e dati di spessore, è stata stimata una perdita di volume di circa 500 milioni di metricubi dalla Piccola Età Glaciale al 1975, che rappresenta il 60% dell'intera massa glaciale. Dal 1975 ad oggi un ulteriore 50% del rimanente volume è stato perso. Stimando la percentuale media annua di variazione volumetrica del ghiacciaio, si nota come tra la Piccola Età Glaciale ed il 1975 risulti una variazione media di $-0,5\%yr^{-1}$, tra il 1975 ed il 1991 il rate di perdita sale a $-1,1\%yr^{-1}$, ed infine tra il 1991 ed oggi è stata stimata una variazione pari a $-2,1\%yr^{-1}$.

TERMINI CHIAVE: Evoluzione glaciale, GPR, dGPS, Bilancio di massa, Ghiacciaio del Rutor, Alpi Italiane.

INTRODUCTION AND GEOGRAPHICAL SETTING

Glaciers retreat is a well-known effect of climate change; glaciers react directly to variations in Temperature

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and Precipitation regime. The most impressive and the easiest effect to be measured is the terminus retreat, which is usually directly related to the mass balance of the ice body itself. But other glaciological parameters are changing, and they can be used for evaluating the «health state» of a glacier under other points of view, to get a more complete view of the glacier evolution. In the last years a multilevel strategy for the glacier monitoring is being developed and internationally used (Haeberli, 2006; Haeberli & *alii*, 2007; UNEP, 2007). This monitoring strategy combines in-situ measurements with remote sensing data and numerical modelling.

In this paper, the recent results deriving from data collected on Rutor glacier during a Ground Penetrating Radar and a GPS survey are analysed. The surveys carried out on the Rutor Glacier can be considered as a part of the integrated approach described above, supporting the regional level of mass balance information.

Rutor Glacier is one of the ten largest glaciers on the Italian side of the Alps. It is located in the Aosta Valley Region, on the Italian-French boundary, which is partly traced on the glacier ice-divide. This glacial body has a present surface of about 800 ha, faces NW and has a quite flat superficial morphology; its maximum altitude reaches 3450 m a.s.l. and its terminus lowest part is situated at an altitude of 2540 m a.s.l.. From a morphological point of view, the Rutor Glacier is divided into two main fluxes by the «Vedette del Rutor» ridge, which develops in SE-NW direction. The conjunction of the two fluxes is visible in the lower part of Rutor glacier, just down valley the «Vedetta Nord» outcrop where it forms a medial moraine.

Many works on Rutor Glacier have been published, some of which concerning the evolution of the glacier from a quantitative point of view. The main sources of presently available data are listed below.

The position of the glacier snout has been surveyed, even not regularly, by the Italian Glaciological Committee since the beginning of the last century (1916). A continuous measurement record, with only minor interruptions, is available starting from 1948, showing that the last retreat of the glacier terminus started in mid '80s. Topographic surveys of the glacier terminus were published by different authors (Bossolasco, 1928; Peretti, 1934; Sacco, 1917), while a reconstruction of the Little Ice Age extension based on morphological evidences was recently published by Orombelli (2005).

A net mass balance of –1710 mm w.e. during 2005-2006 season, regarding the eastern part of the glacier, was computed with glaciological method (FMS, 2006). The network of ablation stakes was extended to the whole glacier at the end of summer 2006.

Finally, a cartographic analysis of frontal and volumetric retreat since the Little Ice Age based on 1:10000 topographic maps and on morphologic reconstructions was published by some of the authors (Villa & *alii*, 2007).

No data have been published up to now either on the volume of the glacier or on the ice thickness. A former GPS assisted GPR survey was carried out in the upper part of the glacier in Summer 1996. The results of such survey, made available by CESI S.p.A. - Milano to the authors, were integrated with a new GPR campaign carried out in summer 2006, so enabling the evaluation of the glacier volume and the mapping of the glacial bed morphology. Moreover, the elevation of the glacier surface provided by GPS along the GPR tracks was compared with a cartography derived DEM of the glacier surface referred to 1991, providing information about ablation amount and distribution within the considered time span.

METHODS AND DATA COLLECTION

The GPR field survey

Ground Penetrating Radar (GPR or Georadar) is a geophysical technique based on the response time of the reflection of an emitted radar impulse. The reflection is related to a change in the dielectric properties of the media crossed by the impulse. In particular, for glaciological purposes, the discontinuity surface of interest is the ice-rock contact (Frassoni & *alii*, 2001). The GPR antenna emits impulses at a constant time interval. A GPR cross session is composed by a series of traces, representing the response of every single impulse emitted through time. The analysis of the reflection times allow, by knowing the velocity of the radar impulse in the media, to calculate the depth of the discontinuity.

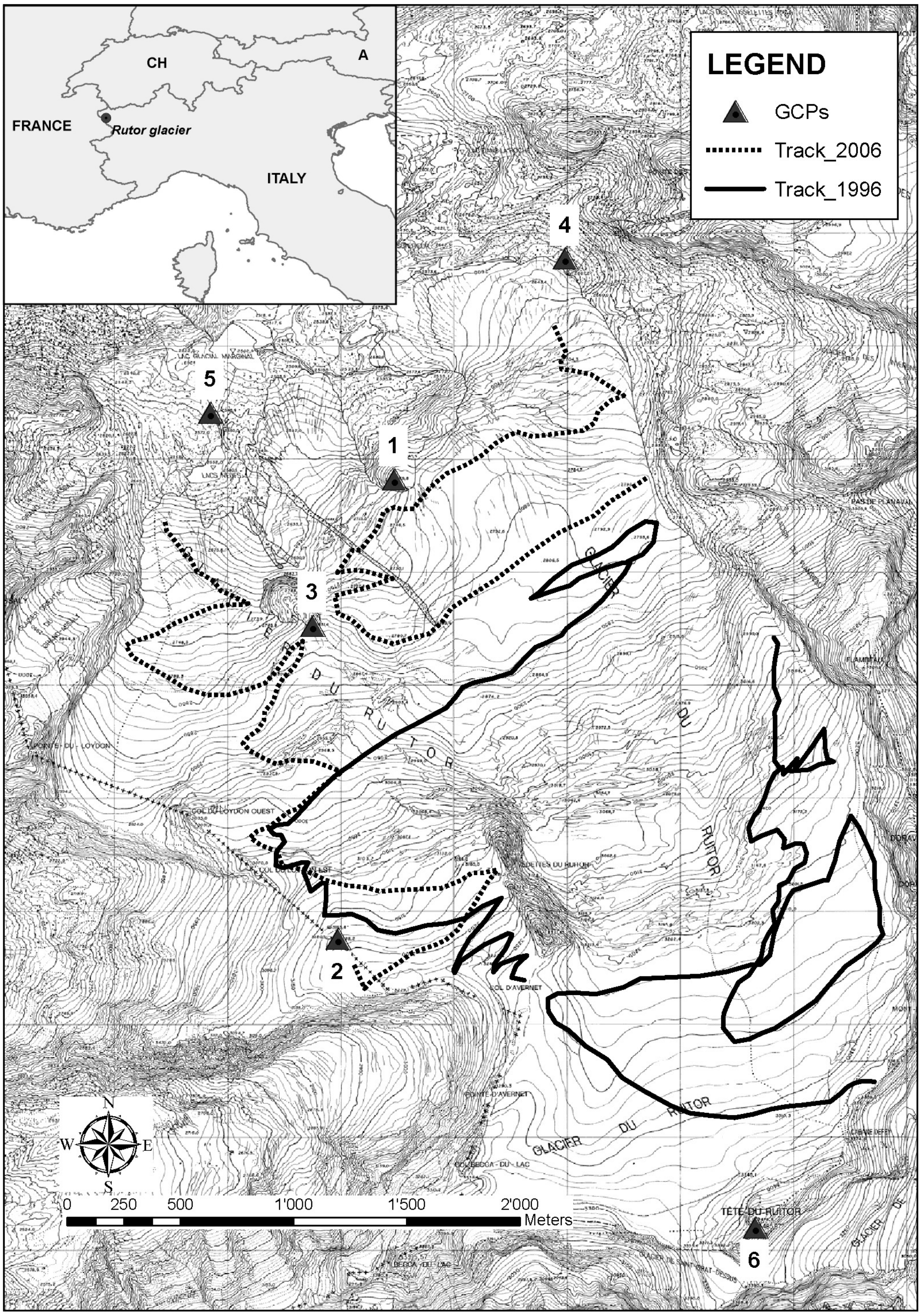
As previously mentioned, a dGPS assisted GPR survey was carried out on Rutor Glacier in July 2006. The aim of the survey was to complete a foregoing survey performed in 1996 mainly on the higher part of the glacier, but never published. Thanks to the new GPR campaign, all the glacier surface where direct access was possible was covered.

A GSSI SIR-3000 radar system and a RADARTEAM Subecho 40 antenna, with 35 MHz centre frequency were used. The choice of this antenna was made after the encouraging results obtained during the investigations carried out on the Adamello Glacier (Frassoni & *alii*, 2001), the Croce Rossa Glacier (Tamburini & *alii*, 2004), the Belvedere Glacier (Tamburini & *alii*, 2003; Tamburini & *alii*, 2005) and the Lys Glacier (unpublished data). A big advantage of this type of antenna is given by its size and weight (1,60 metres long and 6 kg weight), which allow an high portability; this reduces the time spent for the survey and allows a higher freedom to move on the glacier surface.

A differential GPS was used during the survey to georeference the radar data in postprocessing. The path followed during the survey is drawn in fig. 1. Some of the 2006 tracks cross, or even correspond, with the 1996 survey; this choice was made in order to cross check the two surveys, thus avoiding macroscopic systematic errors.

To make the interpretation of the radar signal easier, the survey was carried on by linking opposite sides of the valley, or linking mountainside to outcrops, to obtain cross sections in which ice depth is near zero both at the beginning and at the end.

FIG. 1 - Rutor Glacier survey tracks. The dotted lines represent the GPS-GPR tracks followed during the 2006 survey, while the continuous lines represent the 1996 tracks. The 1996 survey concerns mostly the upper part of the glacier, while the 2006 one is mainly relevant to the terminus area. In the middle-western part of the glacier the two surveys partially overlap: this allowed a comparison between the two interpretations of the radar signals as a control before the data merging. The most problematic area was the one on the east side of the «Vedette del Rutor» rock emergencies, not accessible due to the presence of crevasses. The four new benchmarks positioned in 2006 are the numbers 1 to 4; the number five was created in 1996, while the number 6 is a IGM network topographic vertex. A small location map is shown in the upper left corner.



As shown in fig. 1, the right flux line of the glacier was not completely analysed, both in 1996 and in 2006 survey. The morphology of the glacier area located on the east side of the «Vedette del Rutor» creates some problems with a ground based GPR survey: first of all seracs do not allow to follow an hypothetical straight line to link the eastern side of the glacier to the western one as described before; furthermore seracs (as crevasses) produce many disturbances to the radar signal. The fissures in the ice, cause multiple reflections of the non-vertical radar pulse, which produces high amplitude noises in the response trace, hiding the reflection peak that corresponds to the interface ice-rock. When the emission angle of the radar antenna is not vertical, there is an amount of multiple reflections due to fissures in the ice which is proportional to the amplitude of the emission cone.

The GPS survey

During the GPR survey, differential GPS phase measurements, both static and kinematic, were carried out. The GPS survey had different aims: to create a network of ground control points to be used as ground truth to create surface models from photogrammetric methods, to collect data on the present glacier surface as a starting point for geodetic mass balance purposes (Krimmel, 1999), and to spatially correct the GPR data.

We used the benchmark n° 44 of the Aosta Valley Region network, called «Rifugio Deffeyes» as a base point for the differential correction of the GPS survey. This allowed us to correct the kinematic GPS path and to position four new benchmarks closer to the glacier, that could be used as base points in future surveys. The positions of the new benchmarks are shown in fig. 1.

Acquiring GPS data during the GPR survey allows to derive the bedrock altitude for each point by difference between the surface altitude (GPS) and the ice thickness (GPR). By interpolation of these data it was produced a model of the bedrock surface.

DATA ANALYSIS

Raw GPR data were processed with Sandmeier REFLEXW Software.

Radar traces were processed applying correction algorithms to remove background noise, and to position the start-time of every single trace at the ground level. A mean velocity of 0.17 m/nsec was used to transform the Y-axis of the radar trace from time to ice depth (Popov & *alii*, 2003). To transform the X-axis of the traces from time into space, a geographic correction based on GPS data was used; a series of marker points spaced out by 20 meters each were derived by GPS data and used to apply the transformation.

After the above processing, the original GPR tracks, representing time from start vs travel time, are converted into distance from origin vs ice depth profiles, as shown in fig. 2.

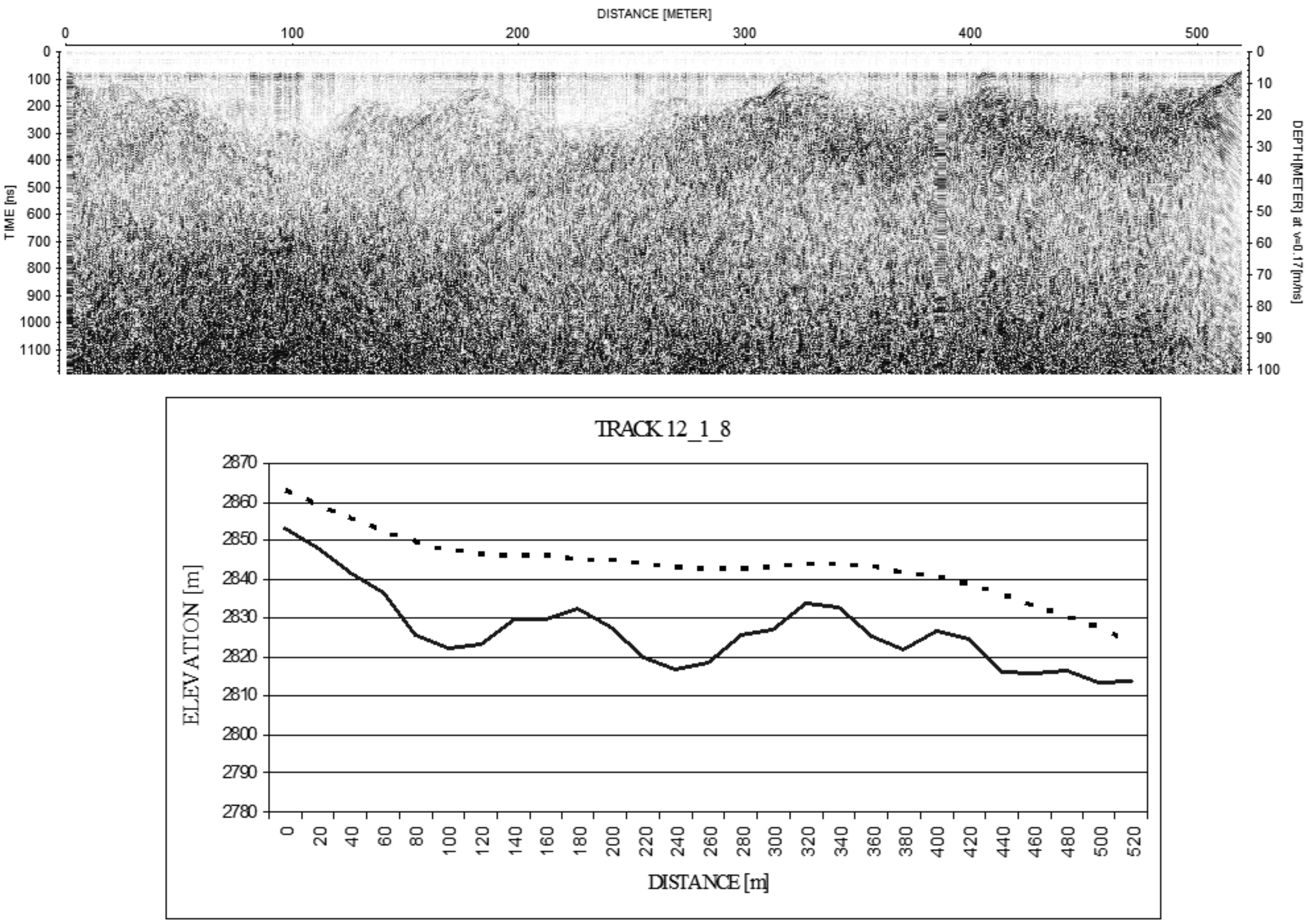


FIG. 2 - An example of radar data plot and their interpretation. In the upper part of the image the X-axis represents the distance from the starting point of the profile (in meters) and the Y-axis represents both Travel Wave Time (left) and depth in meters (right) for a given speed of the signal of 0,17 m/ns. In the lower part of the image a normalized cross section obtained from the above data is shown; the dotted line represents the glacier surface derived from GPS data, while the continuous line represents the bedrock.

After the interpretation of the radar signals and the integration with the GPS data, a cross section representing the surface and the bedrock topography for every track was obtained, as shown in fig. 2. The bedrock elevation data, sampled along the GPR profiles, were used to generate a bedrock surface model by interpolation, using ESRI ArcGIS software.

The GPR survey results were generally good, with evident changes in the radar response under and below the ice-rock discontinuity except for some areas where the signal was very confused, even after some further processing. This happened where the survey path crossed a crevassed area, probably for the multiple reflections due to the ice-air interface or to the presence of interstitial water. In other areas, especially in the north-eastern part of the basin, the signal was very noisy even if there apparently wasn't any relation with crevasses or seracs; this phenomenon is probably due to water presence. In these areas the ice is probably wetter because of the accumulation of meltwater, where, only some tens of meters away, meltwater can easily find a wayout and doesn't interfere with the radar pulse. Moreover, there is no correlation between the noise of the signal and the day time of the survey, in relation to different amount of meltwater.

The match with the 1996 data, after the surface normalization, shows a perfect correspondence between the two independent interpretations where the survey paths cross each other.

In fig. 3 a perspective view of the bedrock model produced after the interpretation of the radar data is shown, while fig. 4 represents the bedrock map of Rutor Glacier.

The ice thickness data were interpolated using a kriging method forced on the average, by dividing the survey area in 5 homogeneous areas. Boundary conditions (zero thickness) were added both on the external and internal (Vedette del Rutor) glacier limit. This approach allowed to complete the model also in the eastern area where data are missing. The resulted model doesn't present particular problems or incongruences, but it has to be noticed that the reconstruction accuracy is inversely proportional to the distance and to the density of the radar data. The resolution chosen for the bedrock model is a 50 m grid. The bedrock reconstruction in the eastern part of the Vedette del Rutor, even if the distribution of the data was not very good, shows a morphology (two slope changes) which is in accordance with the surface evidences (two series of seracs).

Another interesting morphological feature shown by the model is a transversal valley roughly east-west oriented in the lower part of the glacier. The large amount of data in this area allowed the interpolation to reconstruct this structure, which is in accordance with the macromorphologic structure of the area: Rutor valley is in fact characterised by a succession of transversal valleys and ridges (Orombelli, 2005), with the same orientation of the structure identified by the bedrock reconstruction. It is possible that other similar structures exist inside the glacier area but were not identified by the reconstruction because of the inhomogeneous distribution of the GPR data.

After being used to georeference GPR survey, GPS data were used to evaluate ablation along the survey path. The GPS elevation values were compared to a 1991 digital elevation model derived from 1:10000 cartography; this comparison was made even if the accuracy of the two methods is very different (about 10 cm for a kinematic differential GPS survey versus about 2 meters for a 1:10000 cartography derived DTM), but no other differential GPS data are available at the moment. A repetition of the dGPS survey on the same track of 1996 and 2006 in order to approach a geodetic mass balance for Rutor Glacier is planned.

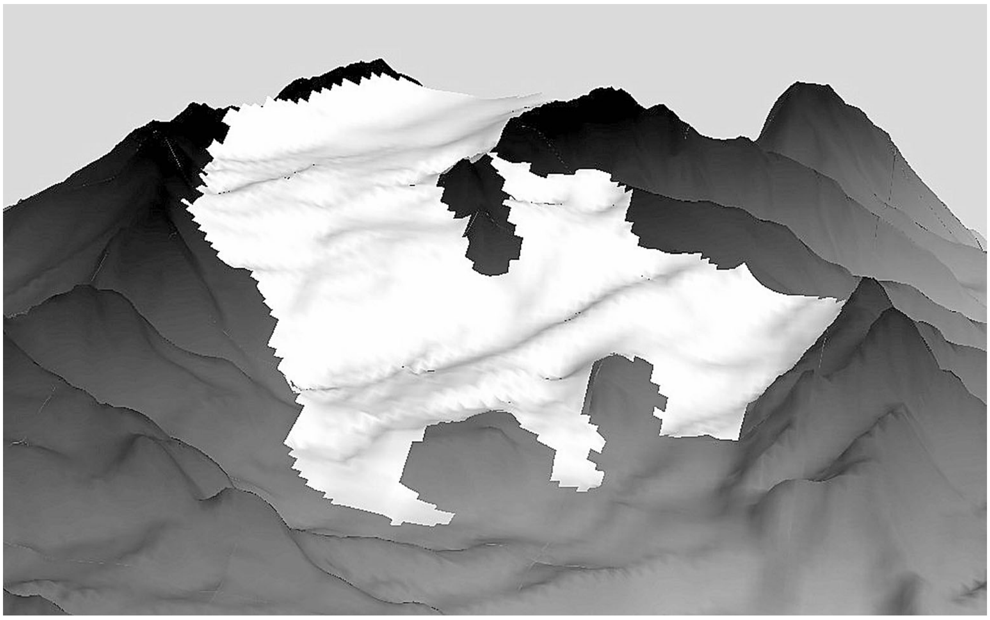


FIG. 3 - Perspective view of the bedrock model of Rutor Glacier. The white area represents the bedrock model below ice. The dark area is a modelling of the surroundings. The perspective and shaded view highlights the morphology of the bedrock and particularly the trench which is right upvalley the glacier terminus.

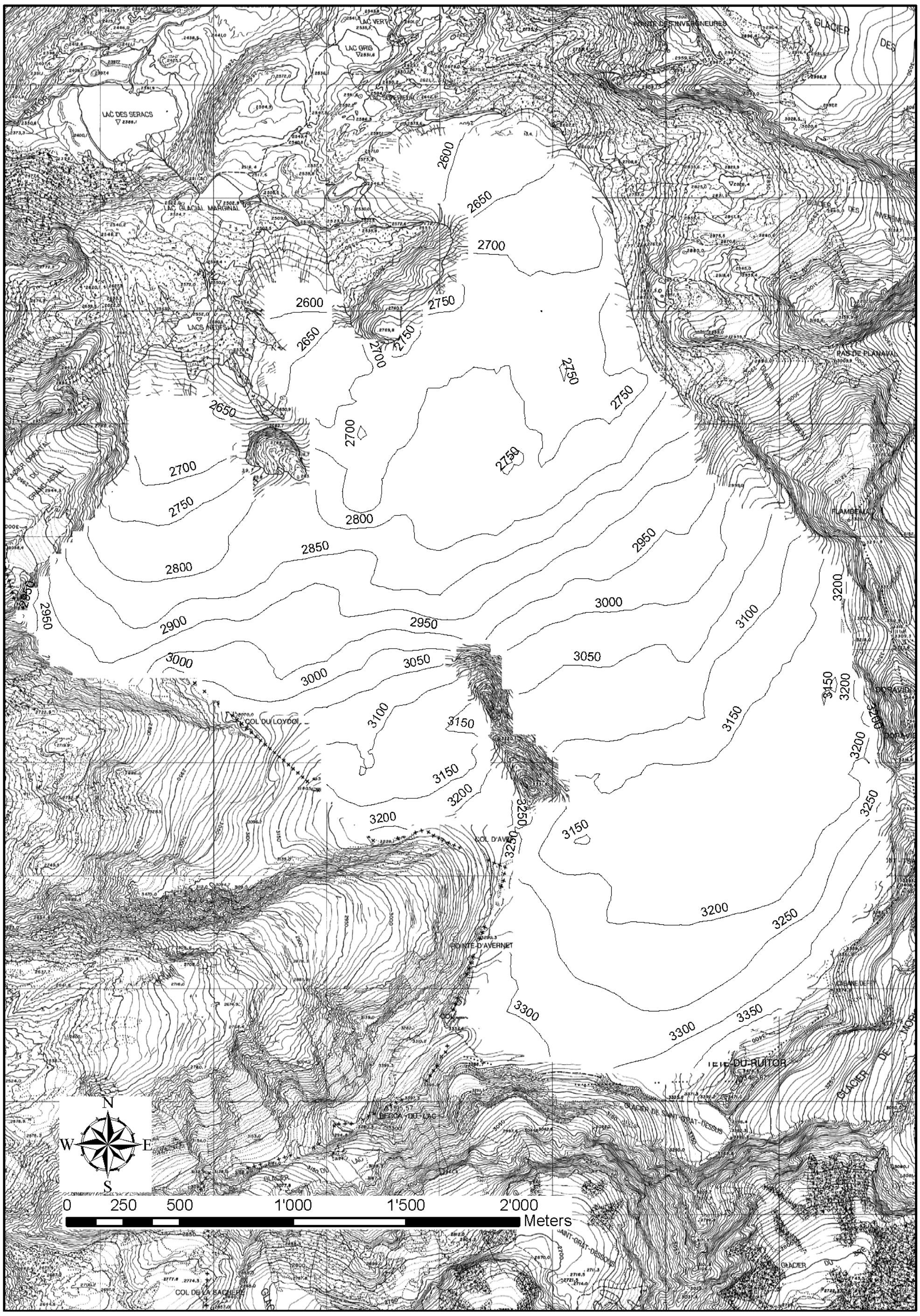


FIG. 4 - Bedrock map of Rutor Glacier obtained after GPR investigations. Contour lines equidistance: 50 meters. The background map is the 1975 Aosta Valley Region Official Map, scale 1:10000.

The comparison between dGPS dataset and the 1991 surface model shows a mean altimetric variation of –10,7 meters (or –10,4 meters w.e.) within less than 15 years.

Other glaciers in the west-alpine area show cumulative mass balances (from 1991 to 2005) which are generally more negative than the one measured on Rutor glacier; Saint Sorlin and Ciardoney both suffered a –17 m w.e. reduction while the Sarennes glacier in the same interval showed a –18 m w.e. reduction (mass balance data published on the WGMS bulletin). While the maximum and minimum elevation of the measured glaciers are reasonably similar, it has to be considered that Rutor glacier faces NW, while Sarennes glacier faces South and Ciardoney glacier faces East.

Once divided the glacier surface in intervals of elevation with a step of 100 m, the mean altimetric variation for each interval was computed and is shown in tab.1. As expected, the trend is a general increase of the thickness loss

TABLE 1 - Mean ablation rate for 100 m altitude intervals in the time interval 1991-2006. 1991 elevation data were derived from a Digital Terrain Model generated on the basis of 1:10000 regional cartography, while 2006 elevation data derive from a kinematic dGPS survey

MEAN ALTIMETRIC VARIATION 1991-2006	
Elevation interval: 2600 - 2700	– 21.7 m
Elevation interval: 2700 - 2800	– 16.0 m
Elevation interval: 2800 - 2900	– 11.8 m
Elevation interval: 2900 - 3000	– 9.7 m
Elevation interval: 3000 - 3100	– 2.7 m
Elevation interval: 3100 - 3200	– 2.8 m

going towards the terminus. Managing the same data in a graphic «altitude vs ice thickness variation», a good correlation between the two variables was obtained (fig. 5). This is a consequence of the continuous retreat period of the glacier in the analysed time interval. The ablation-altitude ratio in this situation is not influenced by the effect of a mass redistribution. On the contrary, if the same analysis is led comparing 1975 and 1991 data, no correlation is found between altitude and thickness loss; in the lower part of the glacier the ice loss turns out to be very low, with an order of magnitude similar to the upper parts. This is due to the effect of the glacial advance of the Eighties, ended in 1986 for Rutor Glacier, as shown by the reports of the yearly glaciological campaign published by the Italian Glaciological Committee.

The 2006 GPS survey didn't concern the upper part of the glacier, so the analysis includes only the area up to 3200 m asl. This area represents the 73% of the total glacier surface, which has a maximum elevation of about 3350 m.

These data show an ice volume reduction of about 10400 mm w.e. in the last 15 years (1991-2006), corresponding to an average ablation rate of about 690 mm/year in the analysed area. The estimated volume loss is 70 x 10^6 m^3 w.e. The whole glacier volume in 1991 was estimated by comparing 1991 surface model (derived by 1:10000 CTR cartography) and the bedrock surface model (derived by GPR data): the total ice volume stored in the Rutor Glacier in 1991 was 222 millions cubic meters (204 x 10^6 m^3 w.e). Assuming no significant ablation or accumulation occurred in the upper part of the glacier (where no data are available), the ice volume loss in the last 15 years would correspond to 33% of the whole glacier volume in 1991.

TABLE 2 - Volume reconstruction of Rutor Glacier during the Little Ice Age maximum, in 1975, in 1991 and in 2006, volume variation in percentage for each time interval and mean annual volume lost in percentage during the three periods

Year	Volume	Δ Volume	Δ Volume/year
LIA	690 * 10^6 m^3	—	—
1975	269 * 10^6 m^3	– 61.0%	– 0,5% yr^{-1}
1991	222 * 10^6 m^3	– 17.5%	– 1,1% yr^{-1}
2006	150 * 10^6 m^3	– 31.5%	– 2,1% yr^{-1}

Starting from the glacier reconstruction in its maximum extent during the Little Ice Age (Orombelli, 2005; Villa & *alii*, 2007) it was possible to estimate the glacier volume retreat, not only by quantifying the ice volume melt but also as a percentage of the total volume.

The volume comparison for the three periods in which it is possible to have a complete model of the glacier (surface and bedrock) shows that between its maximum extent in the Little Ice Age and 1975 Rutor Glacier lost 61% of the total ice volume stored in its basin, from an estimated initial volume of about 690x10^6 m^3 to a volume of about 270x10^6 m^3. Between 1975 and 1991 the volume loss is estimated in 17% of the 1975 ice volume.

It is to notice that the accuracy of the ice volume estimate not only depends on the bedrock reconstruction, which is the same for all the periods, but also on the surface modelling, which differs depending on the kind of data used. The LIA surface model is a morphological reconstruction, the 1975 and 1991 models derive from 1:10000 cartography, and the 2006 volume variation evaluation derives from a spatialization of a dGPS survey.

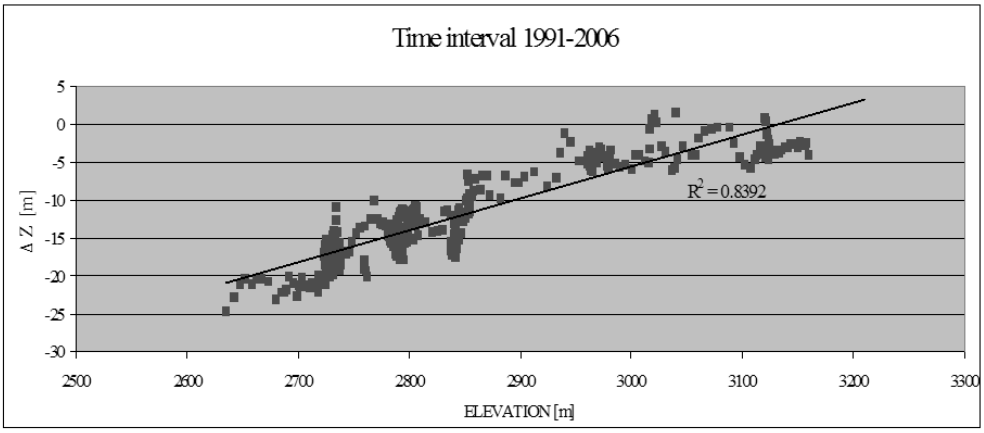


FIG. 5 - Elevation vs ablation in the period 1991-2006. These data derive from the comparison between the dGPS survey of 2006 and the cartography derived DEM of 1991.

CONCLUSIONS

Thanks to the GPR data, the volume of the Rutor Glacier was estimated for three time periods, calculating the difference between the glacier surface model (DEM) and the bedrock model. The analysis made over the last 15 years shows an ablation rate which is in accordance with the Alpine glaciers general trend (WGMS Bulletin, 2005). Although this is not a mass balance, it represents the start point for a series of measures aimed at calculating a mass balance with the geodetic method.

The estimated volume of the glacier during the Little Ice Age maximum, in 1975, in 1991 and in 2006 are shown in tab. 2. An ice volume reduction of about 75% of the initial total volume since Little Ice Age to present days was evaluated. This is only an estimation, since the LIA model used in the calculation is based on a morphological reconstruction of the glacier surface. The mean annual percentage of ice volume loss shows a pronounced increase from about 0,5% per year between Little Ice Age and 1975, to more than 2% per year during the last 15 years. These data completely agree with the same parameters measured for the Alpine glaciers (Haeberli & *alii*, 2007).

Finally, modelling the bedrock can not only be useful to quantify the glacial resource, but can be also used either in flux modelling or in foreseeing the morphological evolution of the ice body.

REFERENCES

BOSSOLASCO M. (1928) - *Studio topografico e stato attuale del ghiacciaio del Rutor*. Bollettino del Comitato Glaciologico Italiano, ser. 1, 8, 23-31.

FMS - Fondazione Montagna Sicura (2006) - *Bilancio di massa del ghiacciaio del Rutor*. http://www.fondazionemontagnasicura.org/crgv2006/start.htm

FRASSONI A., ROSSI G. & TAMBURINI A. (2001) - *Studio del Ghiacciaio dell'Adamello mediante indagini georadar*. Supplementi di Geografia Fisica e Dinamica Quaternaria, 5, 77-84.

HAEBERLI W. (2006) - *Integrated perception of glacier changes: a challenge of historical dimensions.* In: Knight P.G. (ed.), «Glacier Science and Environmental Change». Blackwell, Oxford, 423-430.

HAEBERLI W., HOELZLE M., PAUL F. & ZEMP M. (2007) - *Integrated monitorino of mountain glaciers as key indicators of global climate change: the European Alps*. Annals of Glaciology, 46, 150-160.

KRIMMEL R.M. (1999) - *Analysis of Difference Between Direct and Geodetic Mass Balance Measurements at South Cascade Glacier, Washington*. Geografiska Annaler, 81A, 653-658.

OROMBELLI G. (2005) - *Il ghiacciaio del Ruitor (Valle d'Aosta) nella Piccola Età Glaciale.* Geografia Fisica e Dinamica Quaternaria. Supplementi, 7, 239-251.

PERETTI L. (1934) - *Nuove osservazioni e misure al Ghiacciaio del Rutor.* Bollettino del Comitato Glaciologico Italiano, 14, 173-184.

POPOV V., SHERMEMET'YEV N., MASOLOV N. & LUKIN V. (2003) - *Velocity of radio-wave propagation in ice at Vostok station, Antartica*. Journal of Glaciology, 49, n° 165, 179-183.

SACCO F. (1917) - *Il ghiacciaio ed i laghi del Rutor.* Bollettino della Società Geologica Italiana, 36, 1-36.

TAMBURINI A., MORTARA G., BELOTTI M. & FEDERICI P. (2003) - *L'emergenza del lago Effimero sul Ghiacciaio del Belvedere nell'estate 2002 (Macugnaga, Monte Rosa, Italia). Studi eseguiti, tecniche di indagine utilizzate e principali risultati ottenuti*. Terra Glacialis, 6, 37-54.

TAMBURINI A., MERCALLI L., MORTARA G. & LUCIGNANI M. (2004) - *Glacial risk and reservoir management: the Lago della Rossa reservoir example (Valli di Lanzo, Western Alps, Italy).* Proceedings of the 13th Conference of the British Dam and the ICOLD European Club meeting, Canterbury UK, June 22nd-26th 2004, 408-420.

TAMBURINI A. & MORTARA G. (2005) - *The case of the Effimero Lake at the Monte Rosa (Italian Western Alps): studies, field surveys, monitoring*. IHP-VI, Technical Documents in Hydrology, 77, UNESCO, 179-184.

UNEP (2007) - *Global outlook for Ice and Snow*. UNEP/GRID-Arendal, Norway.

VILLA F., DEAMICIS M. & MAGGI V. (2007) . *GIS Analysis of Rutor Glacier (Aosta Valley, Italy). Volume and Terminus Variations.* Geografia Fisica e Dinamica Quaternaria, 30, 87-95.

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